

Fire Resistance and Structural Behavior of Light Steel Frame (LSF) Walls Under Fire Conditions

Gabriel Kuiava Glufke¹, Paulo A. G. Piloto², Diego R. Rossetto³

^{1,3}Federal Technological University of Paraná (UTFPR), Campus Pato Branco, 85503-390, Brazil.
e-mail: ¹gabrielglufke@alunos.utfpr.edu.br, ³diegorossetto@utfpr.edu.br

²Polytechnic Institute of Bragança (IPB), Campus Santa Apolónia, 5300-253, Portugal.
e-mails: ²ppiloto@ipb.pt

Abstract. This paper investigates the behavior of load-bearing Light Steel Frame (LSF) walls under fire conditions to determine their critical temperature. LSF walls are increasingly used in sustainable building construction. The study compares experimental results from full-scale tests with a 3D numerical model developed to replicate the structural performance under fire.

Three test specimens were analyzed: a smaller one (3x1 m) for load capacity at room temperature, and two larger specimens (3x3 m) tested at 84% and 27% of their load capacity. The 3D numerical analysis involved four simulations: (1) unit load to identify instability and critical loads, (2) geometrical and material nonlinear analysis with imperfections for room temperature capacity, (3) transient thermal analysis to determine temperature over time, and (4) thermomechanical analysis under constant load to assess critical temperature and fire resistance.

Model validation was conducted by comparing experimental and numerical results, with Root Mean Square Error (RMSE) used to quantify temperature differences; RMSE below 100°C indicated good agreement. Results demonstrate that numerical simulations reliably predict load capacity, temperature evolution, and critical temperatures, providing a cost-effective alternative to experimental testing.

Keywords: Light Steel Frame walls, Fire resistance, Numerical simulation.

1. Introduction

Light Steel Framing (LSF) is a sustainable construction system favored for its modularity and efficiency. However, steel's strength declines at high temperatures, necessitating fire resistance studies [1,2]. This work validates a numerical model to predict LSF wall behavior under fire, reducing reliance on costly experiments.

However, steel's strength significantly decreases at elevated temperatures, posing challenges for structural fire resistance [3]. Therefore, both passive protections—such as thermal insulation materials and fire-resistant claddings—and active fire protection systems are essential to safeguard structural integrity and occupant safety, in accordance with standards like EN13501-2 [4,5].

This study aims to validate a finite element numerical model by replicating experimental fire tests on LSF walls. The results demonstrate the potential of numerical simulations as reliable and cost-effective alternatives to physical testing, contributing to safer and more efficient LSF design [6].

2. Materials and Methods

This study investigates the behavior of load-bearing Light Steel Framing (LSF) walls under fire through experimental tests and numerical simulations using the Finite Element Method (FEM).

2.1. Geometry and Experimental Setup

Three LSF wall specimens were tested: one small-scale (P1: 3.00 × 1.00 m) at ambient temperature, and two full-scale (P2 and P4: 3.00 × 3.00 m) under ISO 834 standard fire exposure, loaded at 27% and 84% of the maximum capacity, respectively.

Each wall was composed of cold-formed G550 steel studs (C89×40×12 mm, 1.00 mm thick), spaced at 600 mm, with horizontal noggings at mid-height. The cavity was filled with rock wool insulation (60 kg/m³), and both faces were covered with two 12.5 mm gypsum boards. A steel beam distributed the axial load, and thermocouples monitored temperatures at key locations (gypsum, steel, and insulation). The geometric configuration of the tested LSF walls, including stud spacing, insulation, and board layering, is shown in Figure 1.

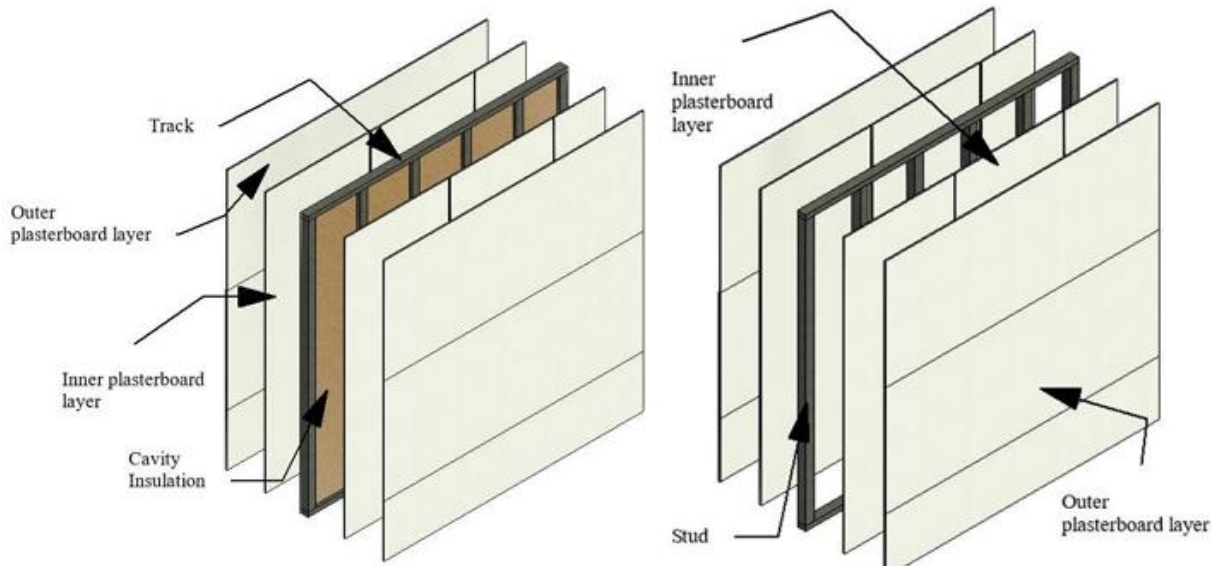


Figure 1 – LSF wall model with and without cavity filling.

Figure 2 presents the CAD model used in both the experimental and numerical stages, including the steel studs, gypsum boards, and insulation layout.

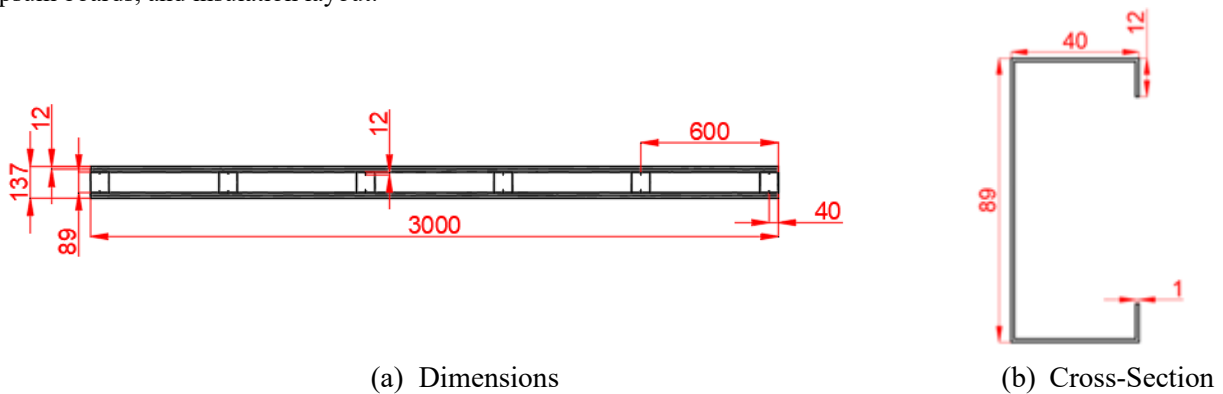


Figure 2 – CAD model of LSF wall.

2.2. Material Properties

Thermal and mechanical properties were defined as temperature-dependent, following Eurocode EN 1993-1-2 [7]:

- a. Steel (G550): Modeled with a bilinear Ramberg-Osgood model with degradation of modulus and yield strength with temperature.

- b. Gypsum: Included dehydration effects around 100 °C.
- c. Insulation: Low thermal conductivity, constant up to 600 °C.

2.3. Numerical Modeling

Numerical simulations were performed in ANSYS APDL with four sequential analyses:

- a. Linear Buckling Analysis (LBA): Identified critical modes to define imperfections.
- b. GMNIA (ambient): Simulated structural response under axial load at room temperature.
- c. Transient Thermal Analysis: Simulated fire exposure per ISO 834, including heat conduction, convection, and radiation.
- d. Thermo-Mechanical Analysis: Evaluated deformations and stresses under combined thermal and mechanical loads, using constant axial load.

Thermal elements (SOLID70, SHELL131) and structural elements (SHELL181) were used. Mesh refinement was applied near joints and interfaces.

2.4. Validation

Three LSF wall specimens were tested:

- a. P1 (3.00 × 1.00 m): Small-scale specimen tested at room temperature to determine maximum axial load capacity.
- b. P2 and P4 (3.00 × 3.00 m): Full-scale walls tested under standard fire exposure ISO 834-1 [8], subjected to 27% and 84% of P1’s maximum load, respectively.

Each wall was composed of cold-formed steel C-profiles (89 × 40 × 12 mm, 1.00 mm thick) made of G550 steel, spaced at 600 mm. The cavity was filled with rock wool insulation (60 kg/m³), and both sides were covered with two layers of 12 mm gypsum plasterboards. Vertical loads were applied using hydraulic jacks and distributed through a top steel beam. Thermocouples were installed at critical points: between gypsum layers, in the steel stud web, and in the insulation core. Table 1 summarizes the axial load-bearing capacities obtained experimentally and through simulation. The numerical model captured trends with deviations below 10%.

Table 1 – Comparison between experimental and numerical load-bearing capacities

Specimen	Max Load (kN) – Experimental	Max Load (kN) – Numerical (FEM)	Difference (%)
P1	99.9	91	-8%
P2	26.7	27.1	-1.5%
P4	84.0	83.5	+0.6%

3. Results and Discussion

This section presents the experimental and numerical results for the load-bearing LSF walls subjected to ambient and elevated temperatures. The discussion includes the structural capacity at room temperature, the thermal response under fire exposure, and the structural behavior during thermo-mechanical analysis.

3.1. Load-Bearing Capacity at Ambient Temperature

At ambient temperature, the numerical model predicted P1’s load capacity (91 kN) within 8% of the experimental value (99 kN), validating the GMNIA approach. Differences stemmed from boundary condition simplifications.

This result indicates good agreement, especially considering the influence of material variability, imperfections, and simplifications in boundary conditions. Figure 3 shows the load–displacement curves for specimen P1, comparing experimental and numerical results. The numerical response closely follows the experimental behavior up to failure.

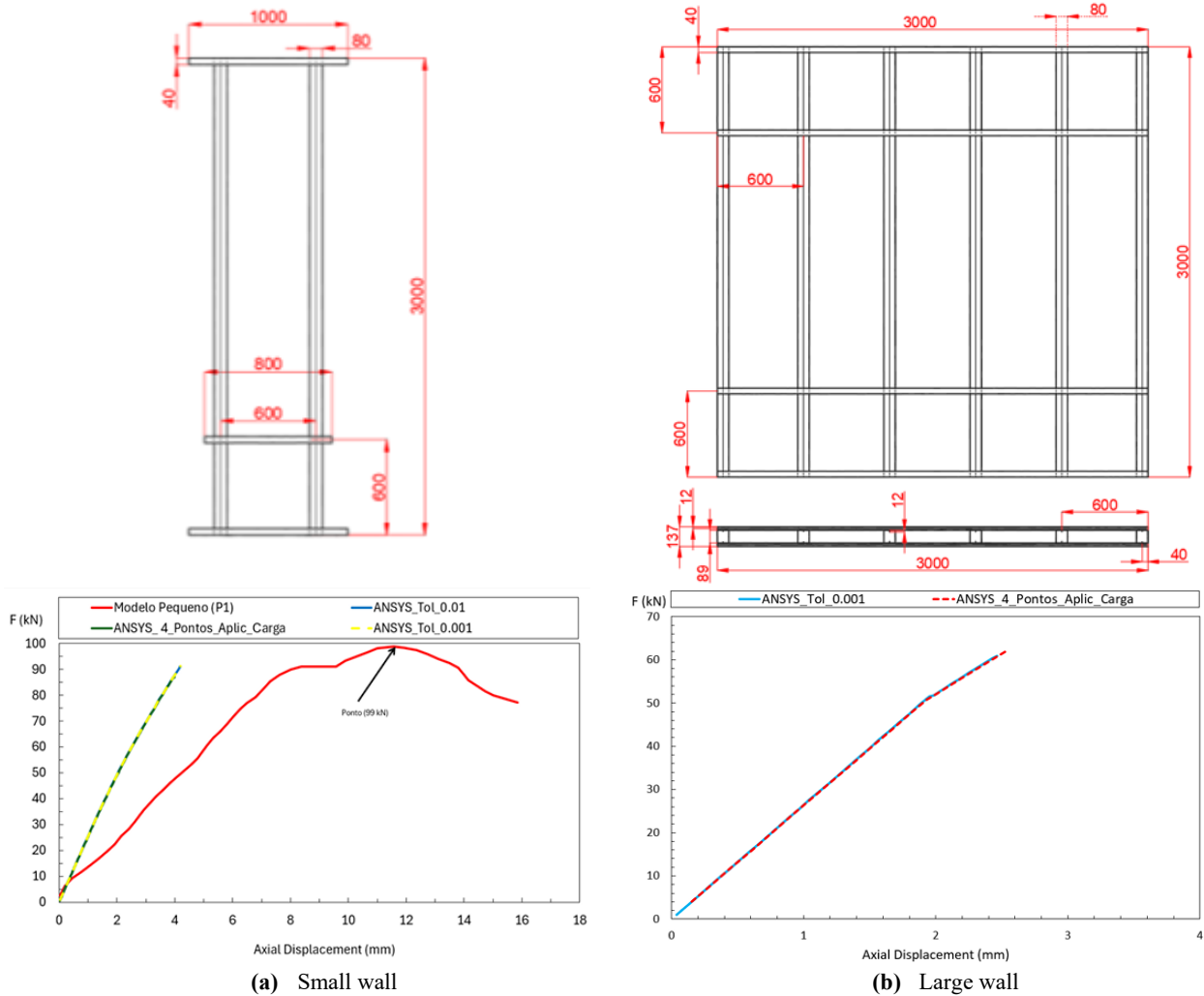
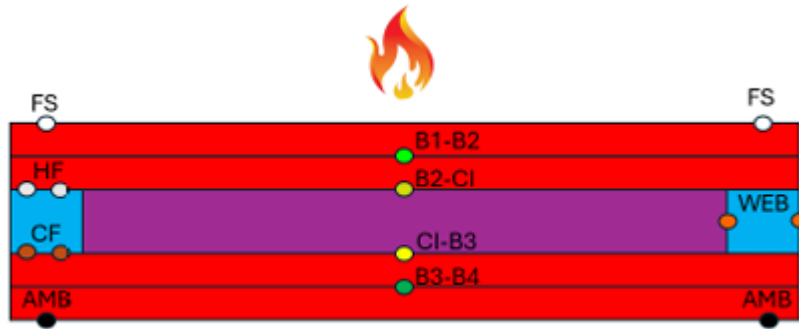


Figure 3 – Load–displacement curve for specimen P1 – Experimental vs. Numerical.

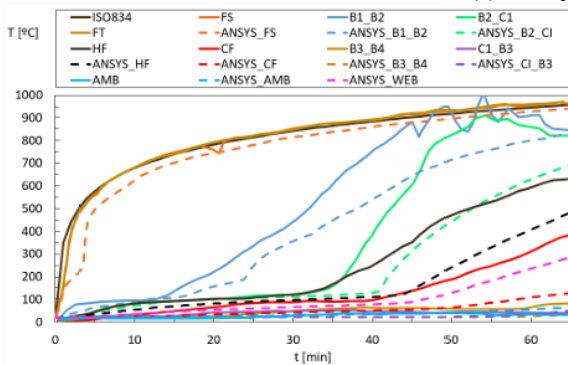
3.2. Thermal Response During Fire Exposure

The transient thermal analysis simulated the heating process under ISO 834-1 [8] standard fire conditions. Temperatures were monitored by thermocouples placed in the gypsum layers, steel studs, and rock wool insulation.

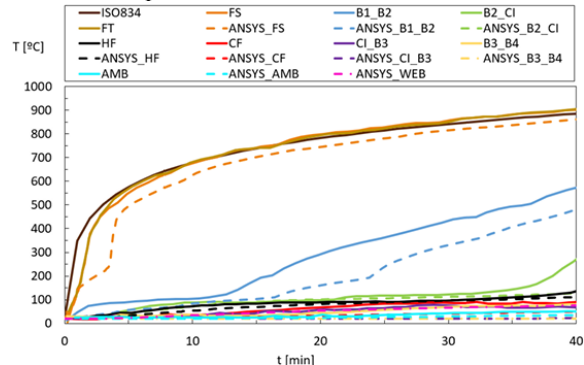
Simulated and experimental temperature curves showed good correlation. The Root Mean Square Error (RMSE) between the results remained below 100 °C, validating the thermal model and material properties used. Figure 4 shows the comparison between measured and simulated temperatures at different heights for models P2 and P4, as illustrated in subfigures (a) to (e). Subfigures (a) and (b) show temperature curves at the top and bottom of P2 and P4, while (c)–(e) display variations along stud height.



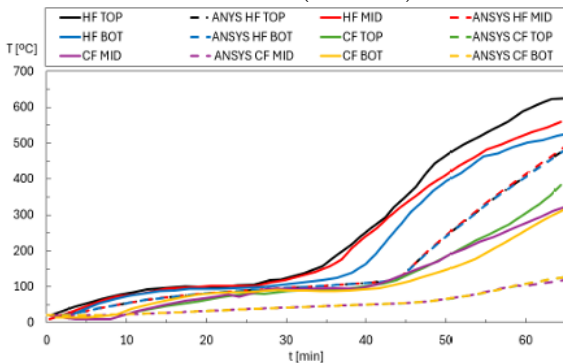
(a) Temperature measurement points



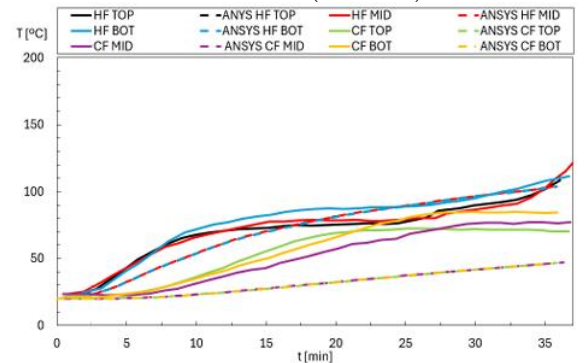
(b) Simulated temperatures at 2500 mm from the base (Model P2)



(c) Simulated temperatures at 500 mm from the base (Model P4)



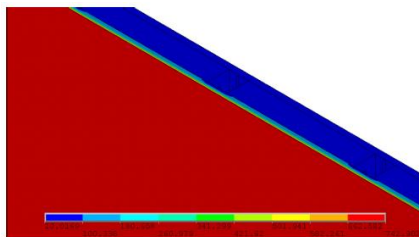
(d) Comparison of simulated temperatures at different stud heights (Model P2)



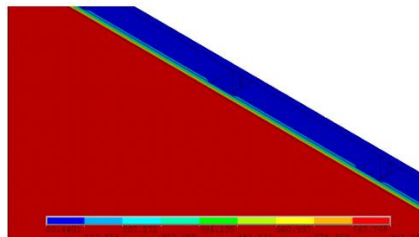
(e) Comparison of simulated temperatures at different stud heights (Model P4)

Figure 4 – Comparison between experimental and simulated temperatures at different sensor heights and locations in the wall structure for Models P2 and P4.

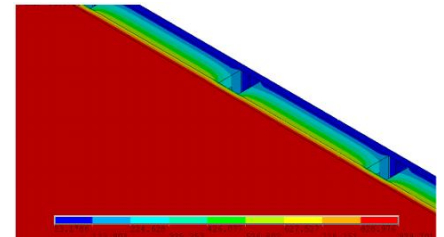
The Figure 5 shows the temperature distribution across the wall section in different minutes of exposure. This visual sequence demonstrates the thermal progression through the wall layers, emphasizing the protective role of the insulation.



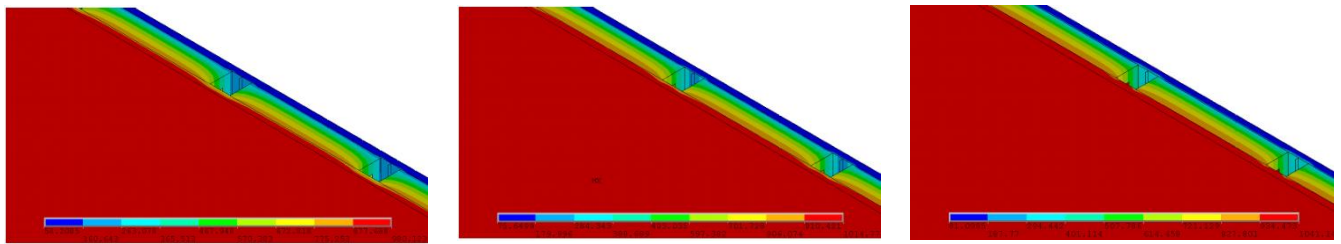
(a) At 20 minutes



(b) At 40 minutes



(c) At 60 minutes



(d) At 80 minutes

(e) At 100 minutes

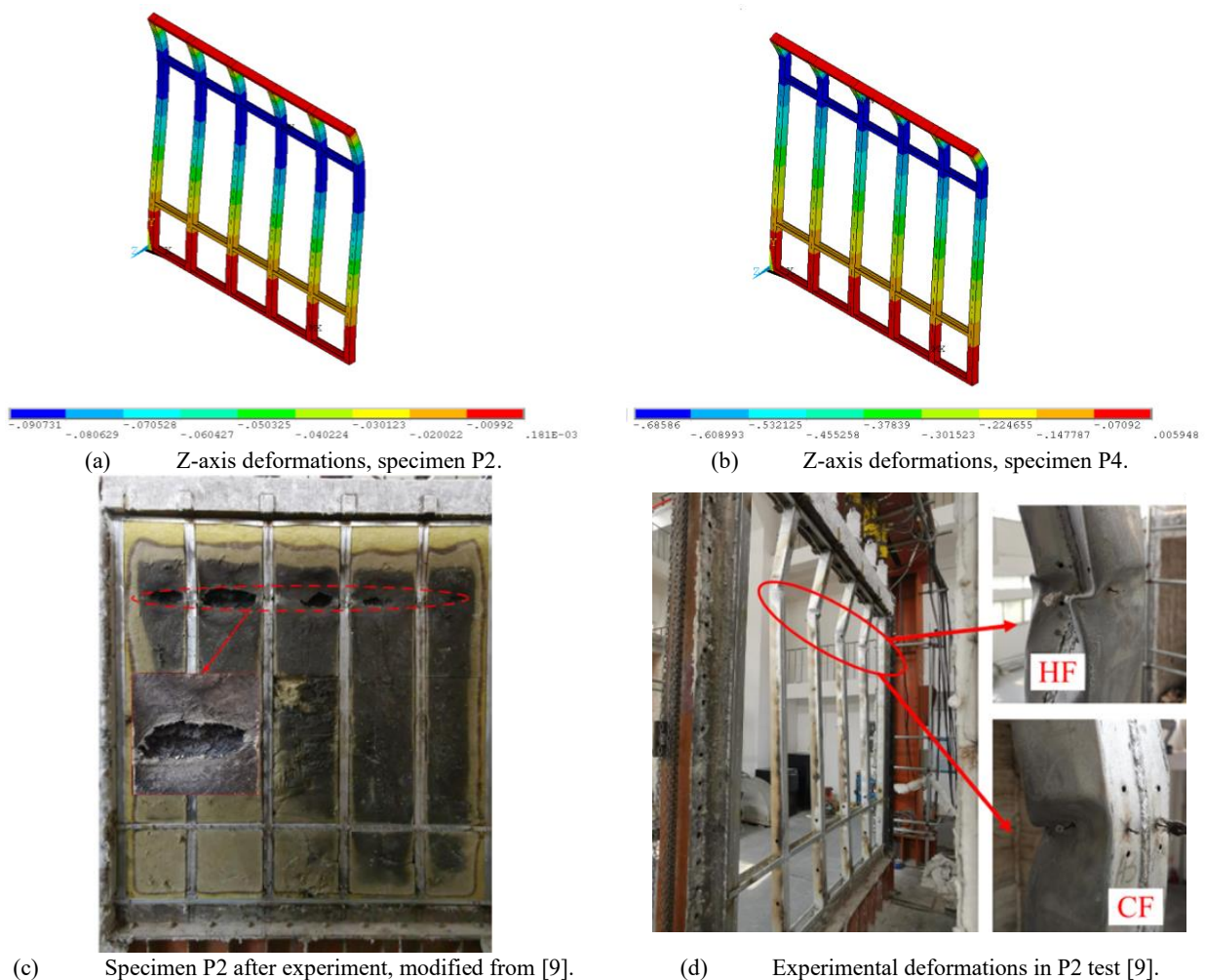
(f) At 120 minutes

Figure 5 – Temperature evolution in the LSF wall cross-section at different simulation times under fire exposure.

3.3. Structural Behavior Under Fire

The full-scale specimens (P2 and P4) were subjected to axial load and fire. Specimen P2, with 27% of its design load, resisted for 69 minutes (experimental) and 70 minutes (numerical). Specimen P4, loaded at 84%, failed after 33 minutes (experimental) and 34 minutes (numerical).

In both cases, failure was characterized by mid-height out-of-plane buckling of the steel studs, triggered when critical temperatures in the steel approached 500–550 °C. The deformation modes observed numerically are consistent with experimental failure patterns, as seen in Figure 6.



(a) Z-axis deformations, specimen P2.

(b) Z-axis deformations, specimen P4.

(c) Specimen P2 after experiment, modified from [9].

(d) Experimental deformations in P2 test [9].

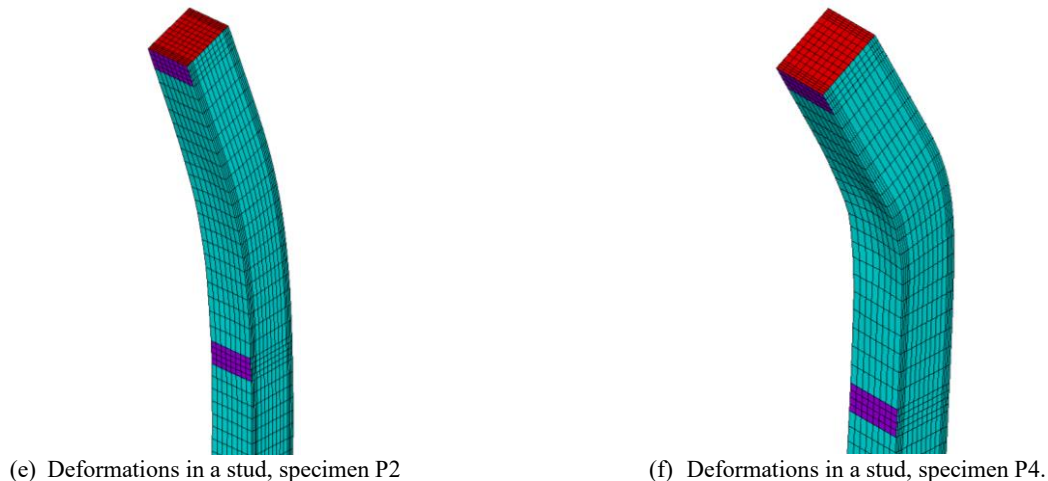


Figure 6 – Deformation in LSF walls at failure (P2 and P4).

4. Conclusion

This study evaluated the behavior of load-bearing Light Steel Framing (LSF) walls under fire conditions using experimental tests and numerical simulations with the Finite Element Method. The GMNIA analysis accurately reproduced the wall's axial load-bearing capacity, with less than 10% deviation from experimental values. Thermal simulations provided temperature curves that closely matched experimental measurements, with RMSE values below 100°C. The structural response under fire conditions, including failure mode and time to collapse, showed consistent results between experimental and numerical methods, with a failure time difference of less than 2 minutes. Overall, the model reliably predicts the behavior of LSF walls in fire, allowing for cost-effective design optimizations. Future research should explore the impact of insulation types and stud spacing on fire resistance.

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